The Simon effect in vocal responses

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Abstract

The Simon effect refers to the finding that faster responses are made to non-spatial stimulus features (e.g., color) when the positions of stimulus and response correspond than when they do not correspond. The usual explanation is that a spatial stimulus code automatically activates a corresponding spatial response code. Recently, however, the Simon effect has also been observed in vocal responses. The present study investigated the properties of Simon effects in the vocal modality. Experiment 1 compared horizontal and vertical Simon effects in vocal responses and found similar patterns of sequential modulations, but different time-courses. Yet the observed results are similar to those described in the literature for manual Simon effects. Experiments 2 and 3 used a dual-task procedure to investigate the impact of manual response codes on the encoding of irrelevant location and the initiation of vocal responses, respectively. Results suggest close links between manual response codes and conceptually corresponding vocal response codes.

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1. Introduction

The notion of stimulus–response (S–R) compatibility addresses the effects that different ways of mapping stimuli on responses have on behavior. In a pioneering article, Fitts and

Symbolic compatibility results from the correspondence between the verbal labels that are associated with the stimulus and the response. If a task contains, for example, green and red stimuli and the vocal responses “green” and “red”, then the corresponding combinations (green–green, red–red) lead to faster responses and fewer errors than the non-corresponding combinations (e.g., Zhang & Kornblum, 1998).

Spatial compatibility is said to occur when the participants have to discriminate the locations of stimuli and the locations of responses on overlapping spatial dimensions. A prototypical task may contain, for example, left and right stimuli and left and right responses. Not surprisingly, spatially corresponding S–R pairings (left–left, right–right) allow for faster responses and higher accuracy than spatially non-corresponding pairings (e.g., Brebner, Shepard, & Cairney, 1972).

The third form of compatibility occurs when the locations of stimuli and responses vary on overlapping dimensions, while participants have to respond to a non-spatial stimulus feature. If, for example, participants give left responses to green stimuli and right responses to red stimuli, while stimulus position varies on the horizontal dimension, then spatially corresponding conditions (green-left S, red-right S) produce better performance than spatially non-corresponding conditions (e.g., Simon & Berbaum, 1990). This observation is called the Simon effect (Hedge & Marsh, 1975; see Lu & Proctor, 1995, for a review).

Most authors assume that the Simon effect arises during response selection (cf. Lu & Proctor, 1995). Explanations of the Simon effect usually distinguish two routes of response activation (Hommel, 1997; Kornblum, Hasbroucq, & Osman, 1990; Zhang, Zhang, & Kornblum, 1999; Zorzi & Umilta, 1995). An indirect (or controlled) route is assumed to process the relevant (non-spatial) stimulus dimension and to activate the correct response in accordance with the instructions. A direct route is assumed to simultaneously process the irrelevant stimulus location and to activate a spatially corresponding response in the current response set. In corresponding conditions both routes activate the correct response. Redundant activation of the correct response facilitates its initiation. In the non-corresponding condition, however, the two routes activate different responses. This response conflict delays execution of the correct response or causes the execution of an incorrect response. In the next section, some significant features of the Simon effect are described.

1.1. Significant features of the Simon effect

As a first feature, the Simon effect is a rather general phenomenon. That is, the Simon effect occurs both for auditory stimuli (e.g., Simon & Rudell, 1967) and for visual stimuli (e.g., Craft & Simon, 1970). Within each stimulus modality, the Simon effect has been found for variations of S–R correspondence on the horizontal dimension (e.g., Hommel, 1993) and on the vertical dimension (e.g., Simon, Mewaldt, Acosta, & Hu, 1976). On the response side, the Simon effect has been observed for stationary keypress responses (e.g., Ansorge & Wühr, 2004; Simon & Rudell, 1967) and for lever movements (e.g., Simon, 1968, 1969).
A second feature of the Simon effect is that the size of the spatial correspondence effect varies with response speed. Such variations are revealed by analysis of reaction-time distributions (e.g., De Jong, Liang, & Lauber, 1994). To perform such an analysis, the RTs of each participant are “vincentized” (i.e., rank-ordered RTs are divided into equally sized quantiles, and the mean RT for each quantile is determined; cf. De Jong et al., 1994; for a critical discussion of this method, see Ridderinkhof, 2002; Zhang & Kornblum, 1997). In an early application of this method, De Jong et al. (1994) observed that both the size of the horizontal Simon effect and the size of the vertical Simon effect decreased when overall RT increased. This pattern of results was attributed to a general decay of automatic response activation. However, later studies found interesting differences between the time courses of horizontal and vertical Simon effects. In a recent study on two-dimensional Simon effects, Proctor, Vu, and Nicoletti (2003) observed an increase of the vertical Simon effect with increasing overall RT, while the horizontal Simon effect remained rather constant across the RT distribution. Rubichi, Nicoletti, Pelosi, and Umiltà (2004) observed similar time courses in a study on two-dimensional spatial correspondence effects. Finally, within the horizontal dimension, Roswarski and Proctor (1996) noticed different time courses of the Simon effect for different relevant stimulus dimensions. In particular, the horizontal Simon effect decreased with increasing RT level when participants responded to stimulus shape. However, the horizontal Simon effect remained rather constant when participants responded to stimulus color. To summarize, it seems well established that the horizontal Simon effect and the vertical Simon effect may have different time courses, although the reason for this difference is not clear.

A third feature of the Simon effect is that the size of the spatial correspondence effect in the present trial is affected by spatial S–R correspondence in the preceding trial. Several studies found large Simon effects after spatially corresponding trials, while the Simon effect was markedly reduced after spatially non-corresponding trials (e.g., Praamstra, Kleine, & Schnitzler, 1999; Ridderinkhof, 2002). Other studies even observed an elimination of the Simon effect after non-corresponding trials (e.g., Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Wühr, 2004). Some authors attributed these sequential modulations of the Simon effect to cognitive mechanisms devoted to the detection and resolution of response conflicts (e.g., Ridderinkhof, 2002; Stürmer et al., 2002). Alternatively, the sequential modulations were explained by assuming that the effects of stimulus and/or response repetitions between subsequent trials would add to the effects of spatial S–R correspondence (e.g., Hommel, Proctor, & Vu, 2004). In any case, larger Simon effects after corresponding than after non-corresponding trials are a stable feature of the Simon effect with manual responses. These modulations have been observed both for horizontal Simon effects (e.g., Hommel et al., 2004; Wühr & Ansorge, 2005) and for vertical Simon effects (e.g., Stürmer et al., 2002; Wühr, 2005).

1.2. The Simon effect in different response modalities

Many authors assume that the Simon effect rests on strong associations between spatial stimulus codes and spatial response codes (e.g., Zhang et al., 1999; Zorzi & Umiltà, 1995). Accordingly, most studies on the Simon effect involved spatial responses like stationary keypresses or joystick movements.Interestingly, however, a recent study observed a Simon effect with vocal responses as well. In this study, Proctor and Vu (2002) investigated spatial correspondence effects in tasks, in which location-relevant and location-irrelevant trials
were presented in random order to the participants. In location-relevant conditions, participants responded to stimulus position by spatially defined responses, and the S–R mapping was varied. In location-irrelevant conditions, participants responded to stimulus color either by keypresses or by saying out loud location words, and stimulus location was varied to provoke Simon effects. One question was how the S–R mapping in location-relevant trials would affect the Simon effect in location-irrelevant trials. With compatible mappings, Proctor and Vu observed normal Simon effects both in manual and in vocal responses. Moreover, with incompatible mappings, the authors observed inverted Simon effects in manual and in vocal responses, with other words, Proctor and Vu found horizontal Simon effects in manual and in vocal responses, which were similarly affected by the S–R mapping in the location-relevant trials.

Proctor and Vu’s (2002) observation of a Simon effect in vocal responses raises the question of how this effect is related to the Simon effect in spatial (i.e., manual) responses. How large is the overlap between the mechanisms that bring about Simon effects in spatial responses and Simon effects in vocal responses, respectively? The investigation of these issues might reveal some insights into the nature of those mechanisms that underlie the impact of irrelevant spatial information on behavior.

1.3. The present study

The present study further investigates vocal Simon effects, which were first demonstrated by Proctor and Vu (2002) for the horizontal dimension. Two general questions are addressed. The first question is whether the Simon effect in vocal responses has similar characteristics as the Simon effect in spatial (i.e., manual) responses. In particular, the present study investigated whether the vocal Simon effect can be observed both for the horizontal and for the vertical dimension. In addition, the present study sought to determine the time course of possible correspondence effects for the horizontal and the vertical dimensions. Finally, the present study investigated whether vocal Simon effects are subject to similar sequential modulations as are manual Simon effects.

The second question addressed in this study concerns the degree of overlap between the mechanisms that produce Simon effects in manual responses and those that produce Simon effects in vocal responses. Are spatial/manual response codes involved in the encoding of location information and/or in the initiation of vocal response codes for location words? These questions are addressed in Experiments 2 and 3, in which a dual-task-like procedure is applied. In each trial of these experiments, participants performed both a manual and a vocal response, and the question was whether the manual response would affect stimulus processing or response initiation in the vocal Simon task.

2. Experiment 1

Experiment 1 investigated the characteristics of the vocal Simon effect for the horizontal and for the vertical dimension. Therefore, one group of participants responded to the colors of stimuli by saying the location words “left” or “right”, and stimuli appeared randomly to the left or right of the screen center. Another group of participants responded to the colors of stimuli by saying the location words “bottom” or “top”, and stimuli appeared randomly below or above the screen center. On the basis of the results of Proctor and Vu (2002), I expected to obtain a Simon effect in vocal responses for the horizontal
dimension. That is, conceptually corresponding conditions (e.g., green-left S—“left” R, red-right S—“right” R) were expected to produce better performance than conceptually non-corresponding conditions (e.g., green-right S—“left” R, red-left S—“right” R). The first aim of the present study was to see whether the vocal Simon effect would also occur for the vertical dimension.

The second aim of the present study was to test whether the vocal Simon effects for the two spatial dimensions would have similar characteristics as the manual Simon effects for the corresponding dimension. In particular, I planned to determine the impact of conceptual S–R correspondence in the preceding trials on the correspondence effect in the current trial. Previous studies have found similar patterns of sequential modulations for horizontal and vertical Simon effects with manual responses (e.g., Hommel et al., 2004; Stürmer et al., 2002). Moreover, I planned to assess the effect of overall RT level on the size of the vocal correspondence effect by means of analyzing RT distributions. Previous studies have found different time courses for horizontal and vertical Simon effects with manual responses (Proctor et al., 2003).

2.1. Method

2.1.1. Participants

Twenty native German speakers (15 female, 5 male), most of them students at the Friedrich–Alexander University, participated in a single-session experiment. Participants had a mean age of 23 years (range 19–35 years). Ten participants were assigned to the horizontal, 10 to the vertical condition. The experiment lasted about 30 min, and each participant was paid 3 Euro. All participants in this and the following experiments were naïve with respect to the purpose of the study and classified themselves as having normal (or corrected-to-normal) visual acuity.

2.1.2. Apparatus and stimuli

Displays were programmed and data collected on an IBM-compatible PC with SVGA graphics and a 17-in. color monitor, using the ERTS software. Vocal RTs were measured with the voice-key provided by ERTS using a standard microphone. Participants’ viewing distance was constrained to 50 cm by a headrest.

Visual stimuli were shown on a black background. The fixation point was a small “+”-sign, subtending approximately 0.3° of visual angle. The stimulus was a red or green solid rectangle with a side length of 16 mm (approximately 1.8° of visual angle). A stimulus appeared to the left or right of the screen center, or it appeared below or above the screen center (see below). At each position, the distance between the inner edge of the stimulus and the screen center was 44 mm (approximately 5.0° of visual angle). Participants responded vocally by speaking into a microphone. The experimenter, who sat in an adjacent room, heard the actual responses through earphones and compared them with a list of the correct responses on a computer screen. Whenever the experimenter detected an erroneous response, he flagged the corresponding trial in a computer file.

2.1.3. Procedure

The experiment began with the presentation of the instructions on the screen. Then, participants practiced their task in a block of 24 trials. The experimental phase contained 10 blocks of 24 trials each. A typical trial consisted of the following sequence of events.
First, the fixation point appeared at screen center, accompanied by a 50-ms warning tone (600 Hz). The fixation point remained for 400 ms and was followed by a 100-ms blank period. Then, a red or green rectangle appeared for 250 ms. In the horizontal condition, the stimulus appeared either to the left or right of the screen center. Moreover, participants were instructed to respond to the stimulus color by saying the German location words “links” (left) or “rechts” (right) as quickly as possible. In the vertical condition, the stimulus appeared either below or above the screen center, and participants were instructed to respond to the stimulus color by saying the German location words “unten” (bottom) or “oben” (top) as quickly as possible. In both conditions (horizontal vs. vertical), the two possible S–R mappings were balanced across participants.

A voice-key registered the onset of the vocal response within a period of 1 s after the onset of the imperative stimulus. If a response had been given within this period, the next trial started after an additional inter-trial interval of 1 s. Hence the stimulus-onset asynchrony (SOA) between two subsequent stimuli was constant at 2500 ms. If the voice-key had not been triggered within the response period, the participants received a corresponding error message that was shown at screen center for one additional second. After each block, the participants could take a rest and start the next block at leisure.

2.1.4. Design

The experiment used a 2(spatial dimension) × 2(S–R correspondence in the preceding trial) × 2(S–R correspondence in the present trial) mixed design. Spatial dimension (horizontal vs. vertical) was varied between participants. Preceding S–R correspondence, and present S–R correspondence was varied within participants. In each block, participants received six repetitions of each combination of two stimulus colors and two stimulus positions. Correspondence conditions had been pre-randomized, to ensure that each of the four possible first-order sequences of correspondence conditions occurred with almost equal probability (58 ± 2).

2.2. Results

For each participant, all RTs exceeding two standard deviations from the grand mean were removed. When averaged across participants in the horizontal condition, RTs < 271 ms (0.5%) and RTs > 714 ms (3.6%) were excluded from further analyses. When averaged across participants in the vertical condition, RTs < 280 (0.7%) and RTs > 849 ms (3.6%) were dropped. Moreover, only RTs from error-free trials that were preceded by an error-free trial were further analyzed. Finally, the first trials in each block were not analyzed because they had no predecessor trials. Except when noted otherwise, one-tailed t-tests were used for planned comparisons.

2.2.1. Response times

Mean RTs for each participant and condition were entered into a 2(spatial dimension) × 2(preceding S–R correspondence) × 2(present S–R correspondence) analysis of variance (ANOVA) for mixed designs. The means are presented in Table 1. The main effect of spatial dimension, $F(1,18) = 2.24$, $p = .15$, was not significant. Yet there were significant main effects of preceding S–R correspondence, $F(1,18) = 4.66$, $MSE = 89.81$, $p < .05$, and of present S–R correspondence, $F(1,18) = 67.05$, $MSE = 210.67$, $p < .001$. The main effect of preceding correspondence indicated somewhat shorter RTs after corresponding
trials (491 ms) than after non-corresponding trials (496 ms), and this effect did not interact with spatial dimension, $F(1,18) = 1.20$, MSE = 89.81, $p = .29$. The main effect of present correspondence revealed the presence of a Simon effect across spatial dimensions. Planned comparisons showed that Simon effects were significant both for the horizontal dimension, $t(9) = 2.65$, $p < .05$, and for the vertical dimension, $t(9) = 8.24$, $p < .001$. A significant two-way interaction between spatial dimension and present correspondence indicated a larger Simon effect for the vertical dimension than for the horizontal dimension, $F(1,18) = 21.86$, MSE = 210.67, $p < .001$.

The two-way interaction between preceding correspondence and present correspondence was also significant, $F(1,18) = 67.05$, MSE = 210.67, $p < .001$. This interaction revealed sequential modulations of the Simon effect across spatial dimensions. In particular, there was a large correspondence effect after corresponding trials ($D = 55$ ms), but no correspondence effect after non-corresponding trials ($D = -2$ ms). When tested separately, the sequential modulation of the Simon effect was significant both for the horizontal dimension, $F(1,9) = 27.84$, MSE = 185.12, $p < .01$, and for the vertical dimension, $F(1,9) = 55.89$, MSE = 206.25, $p < .001$. In particular, there were significant Simon effects after corresponding trials for the horizontal dimension ($D = 34$ ms, $t(9) = 6.41$, $p < .001$) and for the vertical dimension ($D = 76$ ms, $t(9) = 10.29$, $p < .001$). In contrast, after non-corresponding trials there was a small inverted Simon effect for the horizontal dimension ($D = -11$ ms, $t(9) = 1.93$, $p < .05$), and no effect for the vertical dimension ($D = 8$ ms, $t(9) = 1.15$, $p = .14$). Finally, a marginally significant three-way interaction suggested that sequential modulations were somewhat larger for the vertical dimension than for the horizontal dimension, $F(1,18) = 3.23$, MSE = 195.69, $p = .09$.

### 2.2.2. Quintile analyses of RTs

To assess the time course of the correspondence effects in vocal responses, RTs in corresponding and non-corresponding conditions were independently subdivided into quintiles (cf. De Jong et al., 1994). Next, mean RTs were determined for each quintile and entered into a three-factorial ANOVA with spatial dimension as between-subjects factor, and with S–R correspondence and quintile as within-subjects factors. In the following, only the results involving the factor quintile are described. There was, of course, a significant main effect quintile, $F(4,72) = 275.59$, MSE = 1094.72, $p < .001$. Neither the two-way interaction between quintile and spatial dimension nor the two-way interaction between quintile and S–R correspondence was significant (both $F < 1$).

Importantly, however, the three-way interaction was significant, $F(4,72) = 4.15$, MSE = 111.74, $p < .01$, indicating different time courses of Simon effects for the two spatial dimensions. When tested separately, horizontal Simon effects remained rather constant
when overall RT level increased, $F(4, 36) = 2.08$, MSE = 64.79, $p = .10$ (cf. Fig. 1). Planned comparisons (all one-tailed) revealed that the difference between corresponding and non-corresponding conditions was significant for the first ($D = 12\ ms$, $t(9) = 2.76$, $p < .05$), second ($D = 15\ ms$, $t(9) = 6.40$, $p < .001$), third ($D = 12\ ms$, $t(9) = 3.15$, $p < .01$), and fourth quintiles ($D = 10\ ms$, $t(9) = 1.84$, $p < .05$). Yet the 2-ms difference for the fifth quintile was not significant ($t < 1$). In contrast to horizontal Simon effects, vertical Simon effects increased when overall RT level increased, $F(4, 36) = 2.66$, MSE = 158.70, $p < .05$ (cf. Fig. 1). The correspondence effect was smallest for the first quintile ($D = 30\ ms$), and intermediate for the second, third, and fourth quintiles ($Ds = 41, 39, and 44\ ms$), and largest for the fifth quintile ($D = 55\ ms$), all $t(9) > 5.0$, all $p < .001$.

2.2.3. Errors

The low error rates ($M = 1.2\%$, SD = 2.2) were not further analyzed (cf. Table 1).

2.3. Discussion

The results of Experiment 1 revealed that vocal Simon effects do not only occur for the horizontal dimension, but also appear for the vertical dimension. Interestingly, vocal Simon effects were larger for the vertical than for the horizontal dimension. Moreover, vocal Simon effects showed very similar properties as Simon effects with manual responses. Firstly, as are Simon effects with manual responses, Simon effects with vocal responses are present after corresponding predecessor trials, whereas they are reduced or absent after non-corresponding trials. These sequential modulations of manual and vocal Simon effects appear both for the horizontal and for the vertical dimensions. Secondly, analyses of RT distributions revealed different time courses for the horizontal and vertical Simon effects in vocal responses. In particular, the horizontal Simon effect was relatively constant across different levels of overall RT, except for a numerical decrease for the largest quintile (cf. Fig. 1). This result is compatible with observations from studies on Simon effects with

![Graph showing Mean Vocal Simon Effect (ms) vs. Average Bin RT (ms)](image)

Fig. 1. Experiment 1: Correspondence effects (i.e., non-corresponding RT minus corresponding RT) in vocal RTs as a function of overall RT level.
manual responses on the horizontal dimension (e.g., Proctor et al., 2003; Roswarski & Proctor, 1996). In contrast, the vertical Simon effect increased with an increase in overall RT level (cf. Fig. 1). This result is also compatible with observations from studies on Simon effects with manual responses on the vertical dimension (e.g., Proctor et al., 2003).

Many authors have attributed the Simon effect in spatial responses to the fact that a spatial stimulus code almost directly activates a spatially corresponding spatial response code (e.g., Zorzi & Umilta, 1995). The Simon effect in vocal responses suggests that the spatial stimulus code does not only activate spatially corresponding response codes, but activates conceptually corresponding vocal response codes, too. Hence the question arises whether a spatial stimulus code activates spatial response codes and conceptual response codes independently or not. In case of independent activation, performing a response with the left or right hand, while performing the vocal Simon task, should not affect performance in the latter task. This hypothesis was tested in the subsequent experiments.

3. Experiment 2

Experiment 1 showed that the Simon effect with vocal responses has very similar characteristics as the Simon effect with manual responses. This result suggests that spatial stimulus codes do not only activate (spatially corresponding) spatial response codes, but that spatial stimulus codes activate (conceptually corresponding) vocal response codes as well. The following experiments investigate the relationship between spatial response codes representing manual keypress responses and vocal response codes representing location words more closely. For that purpose a dual-task paradigm was created, which required a manual and a vocal response in each trial. A typical trial looked as follows: Participants started a trial by pressing a left or right key and kept this key pressed throughout the whole trial. Then the imperative stimulus for the vocal response appeared. Depending on stimulus color participants had to say “left” or “right” as quickly as possible. Importantly, the horizontal position of the color stimulus varied randomly from trial to trial.

The dual-task method allowed investigating two questions. The first question dealt with the influence of an active spatial/manual response code on the activation of vocal response codes for location words. If spatial/manual response codes are connected to vocal response codes for corresponding location words, then the manual response and the vocal response might interact. Previous investigations found detrimental effects of planned hand actions on the initiation of spatially corresponding foot responses (Stoet & Hommel, 1999). These effects were explained by an overlap between the cognitive structures concerned with the control of different, spatially corresponding actions (see also, Hommel, Müßeler, Aschersleben, & Prinz, 2001). Yet, it is still unclear whether the ongoing execution of a response can effect the concurrent activation of conceptually corresponding vocal response codes. Such an effect would indicate some overlap between spatial/manual response codes and vocal response codes for location words.

The second question concerned the influence of an active spatial/manual response code on the encoding of irrelevant stimulus location. It is possible that the links between spatial stimulus codes and spatial response codes are bi-directional. If so, then the manual response and stimulus location might interact. Previous studies on the effect of planned actions on the encoding of visual information found mixed results. Whereas some authors observed detrimental effects of planned actions on the encoding of conceptually compatible stimuli (e.g., Müßeler & Hommel, 1997; Wühr & Müßeler, 2001), Koch and Prinz...
found no effect of the direction of a planned hand movement on the encoding of the direction of a moving visual stimulus. It is an open question, however, whether the ongoing execution of a manual response might affect the encoding of spatially corresponding locations. The occurrence of such an effect would indicate some overlap between the mechanism for controlling manual responses, and that for encoding locations.

3.1. Method

3.1.1. Participants

Sixteen new students from the Friedrich–Alexander University (12 female, 4 male) participated in a single-session experiment, and received 6 Euro for attendance. Participants had a mean age of 24 years (range 17–36 years); all were native German speakers. None of them had participated in the preceding experiments.

3.1.2. Apparatus and stimuli

Apparatus and stimuli were identical to those used in Experiment 1. In contrast to Experiment 1, however, participants responded vocally and manually in Experiment 2. Manual responses consisted of pressing either the left or the right Control key on a standard computer keyboard.

3.1.3. Procedure

Each trial in Experiment 2 started with a blank period of 500 ms. Next, the message “Left key...” or “Right key...” appeared on the screen until participants pressed the corresponding key. When the participants depressed the instructed key, the fixation cross appeared on the screen and remained there for 1750 ms. Please note that the trial did not start until the correct key had been pressed. Participants were instructed to keep the left or right key depressed as long as the fixation point remained visible. Half a second after the onset of the fixation point, the colored square appeared on the screen for 250 ms, which called for the vocal response “left” or the vocal response “right”. The fixation point disappeared 1000 ms after the offset of the colored square. Finally, there was a further blank period of 500 ms. After an error-free trial the next trial started immediately. If the computer had not registered the response sequence “onset of left or right keypress—vocal response—onset of left or right keypress”, the error message “You released the key too early...or no vocal response registered” was presented on the screen for 2 s. In each other respect, the procedure of Experiment 2 was identical to that of Experiment 1.

3.1.4. Design

Experiment 2 rested on a three-factorial within-subjects design. The experimental factors were manual response (left vs. right), stimulus position (left vs. right) and vocal response (left vs. right). Each combination of the different levels of the three factors appeared with equal frequency. The experiment was run in 11 blocks of 24 trials each. The first block was considered practice and, therefore, not analyzed.

3.2. Results

Across participants, trials with RTs < 251 ms (2.1%) and RTs > 984 ms (4.1%) were excluded from further analyses.
3.2.1. Response times

Mean RTs were entered into a 2(manual response) × 2(stimulus position) × 2(vocal response) ANOVA. The corresponding means are shown in Fig. 2. There were two results. Firstly, the two-way interaction between stimulus position and vocal response was significant, \( F(1,15) = 8.99, \) \( \text{MSE} = 486.13, \) \( p < .01. \) The interaction signaled the presence of a Simon effect in vocal responses: The vocal “left” response was faster to left stimuli than to right stimuli (586 vs. 593 ms), and the vocal “right” response was faster to right stimuli than to left stimuli (584 vs. 601 ms). Secondly, the two-way interaction between manual response and vocal response was also significant, \( F(1,15) = 5.63, \) \( \text{MSE} = 380.93, \) \( p < .05. \) The interaction indicated a negative effect of response–response correspondence. In particular, the vocal “left” response was slower during a left keypress than during a right keypress (593 vs. 586 ms), and the vocal “right” response was slower during a right keypress than during a left keypress (597 vs. 588 ms). None of the remaining \( F \)-tests approached significance (\( F = 2.67, \) \( p = .12, \) for the three-way interaction; \( F < 2.0, \) \( p > .15, \) for the remaining tests).

3.2.2. Errors

The low error rates (\( M = 1.8, \) \( \text{SD} = 1.8 \)) were not statistically analyzed. Yet the error percentages showed the same numerical pattern as the RT results.

3.3. Discussion

Experiment 2 investigated the effects of active spatial/manual response codes on the encoding of irrelevant stimulus location, and on the activation of vocal response codes for location words, respectively. Stimuli and responses varied on the horizontal dimension. The first result was a vocal Simon effect under dual-task conditions. More interesting are the results with regard to the effects of manual responses. The ongoing execution of a left or right key press had no effect on the encoding of irrelevant stimulus location. This does not mean that such effects do not exist at all. Rather the results of previous studies suggest
that presenting the visual stimuli near threshold may be an important pre-condition for observing effects of actions on concurrent visual encoding (e.g., Jolicoeur, 1999). Yet this condition was not met in Experiment 2. Moreover, it is also possible that RTs are less sensitive than accuracy scores for measuring the effects of actions on perception.

The ongoing execution of a left or right key press had a specific effect on the initiation of vocal responses. In particular, the execution of a manual response slowed the concurrent initiation of a conceptually corresponding vocal response. This observation is consistent with, but goes beyond previous results of Stoet and Hommel (1999). While these authors found detrimental effects of planned hand actions on the initiation of spatially compatible foot responses, the present results revealed interference between the ongoing execution of manual responses and the initiation of compatible vocal responses. The latter result suggests a close relationship between manual response codes and vocal response codes for location words.

A problematic aspect of the results of Experiment 2 is that the effects were rather small. Therefore, Experiment 3 aimed at replicating the results of Experiment 2.

4. Experiment 3

The goal of Experiment 3 was to replicate the results of Experiment 2. Experiment 3 was almost identical to Experiment 2, except for the fact that stimuli and responses varied on the vertical dimension. I expected a vocal Simon effect for the vertical dimension. The question was whether the concurrent execution of a manual response would again interfere with the initiation of a conceptually corresponding vocal response.

4.1. Method

4.1.1. Participants

Sixteen new students from the Friedrich–Alexander University (11 female, 5 male) participated in a single-session experiment, and received 6 Euro for attendance. Participants had a mean age of 24 years (range 20–35 years).

4.1.2. Apparatus and stimuli

Apparatus, stimuli and procedure were similar to those used in Experiment 2, except for the following changes. Stimuli and responses varied on the vertical dimension in Experiment 3. Manual responses consisted of pressing either the “↑” or “↓” key with the right index finger on a standard computer keyboard. Visual stimuli appeared in green or red color either to the top or to the bottom of the screen. Vocal responses were the words “bottom” or “top” to the colors of the visual stimuli. Half of the participants said “bottom” to green stimuli, and “top” to red stimuli; the other half of the participants followed the opposite mapping.

4.1.3. Design

The design of Experiment 3 was identical to that of Experiment 2.

4.2. Results

Across participants, trials with RTs < 194 ms (0.4%) and RTs > 1012 ms (4.7%) were excluded from further analyses.
4.2.1. Response times

RTs were entered into a three-factorial ANOVA, with manual response, stimulus position, and vocal response as within-subjects factors. The means are shown in Fig. 3. There were three results. Firstly, there was a significant main effect of stimulus position, $F(1,15) = 11.94$, $MSE = 464.02$, $p < .01$, indicating faster responses to top stimuli (505 ms) than to bottom stimuli (563 ms). Secondly, the two-way interaction between stimulus position and vocal response was significant, $F(1,15) = 19.30$, $MSE = 1064.98$, $p < .01$. This interaction represented a Simon effect in vocal responses: The “bottom” response was faster to bottom stimuli than the “top” response (552 vs. 575 ms), and the “top” response was faster to top stimuli than the “bottom” response (536 vs. 564 ms). Thirdly, the two-way interaction between manual response and vocal response was also significant, $F(1,15) = 6.44$, $MSE = 678.83$, $p < .05$. The interaction indicated a negative effect of response–response correspondence. That is, the vocal “bottom” response was significantly slower during a lower keypress than during an upper keypress (566 vs. 550 ms), and the vocal “top” response was slower during an upper keypress than during a lower keypress (560 vs. 552 ms). None of the remaining $F$-tests approached significance (all $F < 1.5$, all $p > .24$).

4.2.2. Errors

The low error rates ($M = 2.6$, $SD = 3.2$) were not statistically analyzed. Yet the error percentages showed a similar numerical pattern as the RT results.

4.3. Discussion

The results of Experiment 3 replicate and extend the results of Experiment 2. Firstly, the vocal Simon effect for the vertical dimension was also observed under dual-task conditions. Secondly, the execution of manual keypresses left the encoding of irrelevant location information again unaffected. Thirdly, the execution of manual keypresses again impaired the initiation of conceptually corresponding vocal responses, suggesting tight links between spatial response codes and vocal response codes for location words.

![Fig. 3. Experiment 3: Vocal RTs as a function of stimulus position, position of the manual response, and vocal response.](image)
Finally, a further result of Experiments 2 and 3 should be mentioned. In particular the vertical Simon effect in Experiment 3 ($D = 36$ ms) tended to be larger than the horizontal Simon effect in Experiment 2 ($D = 12$ ms; $F[1,30] = 4.07$, MSE = 192.41, $p = .053$). This observation confirms a similar result of Experiment 1.

5. General discussion

The present study had two aims. The first aim was to compare the characteristics of the vocal Simon effect to the characteristics of the spatial/manual Simon effect, which are known from the literature. The second aim was to investigate the role of spatial/manual response codes for the encoding of irrelevant location information, and for the activation of vocal response codes for location words, respectively.

The results of Experiment 1 revealed that the vocal Simon effect has similar properties as the “classical” Simon effect with manual responses. In particular, vocal and manual Simon effects arise for the horizontal and the vertical dimensions. Furthermore, vocal and manual Simon effects are subject to sequential modulation. That is, Simon effects are relatively large after corresponding trials, and they are reduced or absent after non-corresponding trials. Sequential modulations of vocal and manual Simon effects arise for the horizontal and the vertical dimensions. Finally, vocal and manual Simon effects show different time courses for the two spatial dimensions. Correspondence effects for the horizontal dimension remain rather constant when overall RT level increases (Proctor et al., 2003; Roswarski & Proctor, 1996). Yet correspondence effects for the vertical dimension increase with increasing RT level (Proctor et al., 2003; Rubichi et al., 2004).

A possible explanation for the different time courses of horizontal and vertical Simon effects may be that horizontal codes are activated more quickly than vertical codes. A possible reason for this difference in activation speed may be that horizontal stimulus location is encoded in more than one frame of reference simultaneously, while vertical position is encoded in only one frame of reference (cf. Rubichi, Nicoletti, & Umiltà, 2005). The similarity of vocal and manual Simon effects suggests that similar mechanisms underlie these correspondence effects. This calls the categorical distinction between Simon effects and semantic compatibility effects—as proposed by Simon et al. (1981)—into question.

Experiments 2 and 3 investigated the role of spatial response codes for the encoding of irrelevant location information, and for the activation of conceptually corresponding vocal response codes, respectively. In these dual-task experiments participants responded to the color of visual stimuli by saying a location word, while pressing a key. The correspondence between visual stimulus location and vocal response, the correspondence between manual response location and visual stimulus location, and the correspondence between manual response location and vocal response varied independently. Experiment 2 (horizontal dimension) and Experiment 3 (vertical dimension) revealed three consistent results. Firstly, there was a vocal Simon effect under dual-task conditions. Secondly, there was no effect of manual response location on the encoding of irrelevant stimulus location. Thirdly however, there was a detrimental effect of manual response execution on the initiation of conceptually corresponding vocal responses.

The results of the present studies have implications for our understanding of Simon effects. These implications mainly concern the nature of the response codes that receive activation from the spatial stimulus codes. The dominant explanation for the Simon effect with spatial responses is that a spatial stimulus code automatically activates a spatially
corresponding response code. By analogy, the Simon effect with vocal responses should arise because a spatial stimulus code automatically activates a conceptually corresponding vocal response code. It is unclear, however, whether the spatial stimulus code activates manual or vocal response codes directly or indirectly. The results of Experiments 2 and 3 favor the latter possibility. That is, these results suggest that the spatial stimulus code activates an abstract cognitive response code that represents the alternative responses on a cognitive level by a salient feature (Ansorge & Wühr, 2004; Hommel, 1993). This cognitive code, in turn, activates manual or vocal response (motor) codes.

On the basis of these assumptions the results of Experiments 2 and 3 can be explained as follows: The vocal Simon effect arises from the fact that irrelevant stimulus location produces a code in working memory. This code automatically activates a conceptually corresponding response code in working memory. Simultaneously, a cognitive code for stimulus color activates the instructed response code. In corresponding conditions, automatic and instruction-dependent processing converges on the same response code, whereas a response conflict arises in non-corresponding conditions. Yet before the correct response can be executed, the activated codes must be integrated into an action plan (Hommel, 1998; Hommel et al., 2001). This integration process is impaired (i.e., slowed down) when the cognitive codes, which represent the features of the intended action, are already bound into existing action plans (Stoet & Hommel, 1999; Wühr & Müsseler, 2001). This is the case, for example, when the participant already presses a left key while he/she has to say “left” to a green stimulus. In this case the cognitive response code LEFT is already bound into the action plan for the manual response, which delays formation of an action plan for the vocal response.

Finally, the observation of larger vocal Simon effects for the vertical dimension than for the horizontal dimension should be discussed. This result was significant in Experiment 1, and marginally significant, when the results of Experiments 2 and 3 were compared. With regard to spatial correspondence effects with manual responses, the existence of such prevalence effects is a matter of debate. Some authors claim an a priori prevalence of the horizontal dimension over the vertical dimension (e.g., Rubichi et al., 2004, 2005). Other authors postulate that any imbalance in the salience of two spatial dimensions may lead to prevalence effects in either direction (e.g., Proctor et al., 2003). The results of the present experiments do not favor the claim for an a priori prevalence of the horizontal dimension. Yet the vertical prevalence effects may have resulted from the different salience of the stimulus dimensions. In the present studies, horizontal and vertical stimulus locations were equally distant from the screen center. Yet, as a result of the rectangular shape of the screen, vertical locations are closer to the edge of the screen than horizontal locations. This fact might have increased the salience of vertical locations, and therefore produced the vertical prevalence effects.

In summary, the results of the present study suggest that the Simon effect does not arise from spatial stimulus codes directly activating corresponding motor codes, but from the interaction of relatively abstract conceptual codes. Therefore, the emergence of the Simon effect is not restricted to a particular response modality.

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